Baryon-strangeness correlations: a diagnostic of strongly interacting matter

V. Koch, A. Majumder, and J. Randrup

[1] *Nuclear Science Division, Lawrence Berkeley National Laboratory, Berkeley, California 94720*

The principal goal of high-energy heavy-ion collisions is the creation and exploration of a state of matter in which the pervasive degrees of freedom carry color charges. While the picture of a weakly interacting plasma of quarks and gluons is supported qualitatively by the rapid rise in the entropy density as obtained by lattice QCD calculations, the fact that the high-T behavior falls somewhat below that of an ideal gas of massless quarks and gluons, indicates that the chromodynamic plasma has a more complex structure.

We propose an observable [1] to discern the relevant degrees of freedom and their correlations. Consider a situation in which the basic degrees of freedom are weakly interacting quarks and gluons. Then strangeness is carried exclusively by the s and $\bar{s}$ quarks which in turn carry baryon number in strict proportion to their strangeness, $B_s = -\frac{1}{3}S_s$, thus rendering strangeness and baryon number strongly correlated. This feature is in stark contrast to a hadron gas in which the relation between strangeness and baryon number is less intimate. For example, at small baryon chemical potential the strangeness is carried primarily by kaons, which have no baryon number.

As a result we introduce the following correlation coefficient,

$$C_{BS} \equiv -3\frac{\sigma_{BS}}{\sigma_S^2} = -3\frac{\langle BS\rangle - \langle B\rangle\langle S\rangle}{\langle S^2\rangle - \langle S\rangle^2} = -3\frac{\langle BS\rangle}{\langle S^2\rangle}. \qquad (1)$$

The average $\langle\cdot\rangle$ is taken over a suitable ensemble of events and the last expression uses the fact that $\langle S\rangle$ vanishes. When the active degrees of freedom are individual quarks, the total strangeness is $S = \nu_{\bar{s}} - \nu_s$, while the baryon number can be expressed as $B = \frac{1}{3}(U + D + S)$, where $U = \nu_u - \nu_{\bar{u}}$ is the upness and $D = \nu_d - \nu_{\bar{d}}$ is the downness. Thus, if the flavors are uncorrelated, we have $\sigma_{BS} = -\frac{1}{3}\sigma_S^2$ and C_{BS} is unity.

In a gas of hadron resonances, the total baryon number is $B = \sum_k n_k B_k$ and its total strangeness is $S = \sum_k n_k S_k$, where the species k has baryon number B_k and strangeness S_k. If no prior correlations are present, the correlation coefficient may then be expressed in terms of the multiplicity variances $\sigma_k^2 \equiv \langle n_k^2\rangle - \langle n_k\rangle^2 \approx \langle n_k\rangle$,

$$C_{BS} \;=\; -3\frac{\sum_k \sigma_k^2 B_k S_k}{\sum_k \sigma_k^2 S_k^2} \;\approx\; -3\frac{\sum_k \langle n_k\rangle B_k S_k}{\sum_k \langle n_k\rangle S_k^2}\,. \qquad (2)$$

The numerator receives contributions from only (strange) baryons, while the denominator receives contributions also from (strange) mesons, At the relatively high temperatures relevant at RHIC, the strange mesons significantly outnumber the strange baryons, so C_{BS} is smaller than unity, we find $C_{BS} = 0.66$ for $T = 170$ MeV and zero chemical potential, $\mu_B = 0$.

The correlation coefficient may also be derived from lattice calculations where, it may be expressed as a ratio of susceptibilities, $C_{BS} = -3\chi_{BS}/\chi_{SS}$. At $\mu_B = 0$, and using values for the mixed susceptibilities derived from lattice calculations, we obtain a $C_{BS} \approx 1$, suggesting that the quark flavors are uncorrelated, as in the ideal quark-gluon plasma. (However, the presence of pure gluon clusters cannot be ruled out by this diagnostic.)

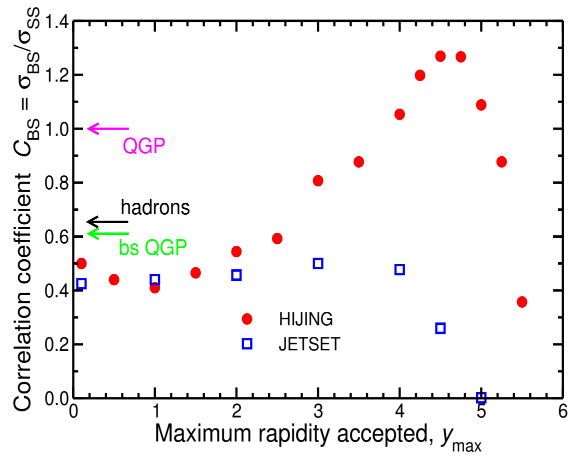

FIG. 1: The correlation coefficient C_{BS} obtained with HIJING from generated samples of 10,000 Au+Au events at the top RHIC energy of $\sqrt{s} = 200A$ GeV, shown as a function of the maximum rapidity accepted, $|y| \leq y_{\max}$. Also shown is the corresponding results for e^+e^- at $\sqrt{s} = 200$ GeV calculated with JETSET. The arrows point to the values obtained for the ideal quark-gluon plasma, the hadronic gas at $T = 170$ MeV, and the bound-state QGP .

Recently there has appeared a model that purports to explain both the equation of state as obtained on the lattice as well as the large flow observed in heavy-ion collisions. This model describes the chromodynamic system as a gas of massive quarks, antiquarks, and gluons together with a myriad of their bound states generated by a screened Coulomb potential. In order to assess the consistency of this model with present lattice results, we estimate the ratio C_{BS} in such a scenario. For details of this estimation and the underlying model see Ref. [1]. The resulting value obtained at $T = 1.5T_c$ is $C_{BS} = 0.62$. The fact that it differs significantly from the value extracted directly from lattice QCD (see above) suggests that the bound-state model is perhaps not suggestive of the dynamical picture of an excited chromodynamic system.

In order to estimate the rapidity dependence of such a ratio, we have extracted C_{BS} from events generated by HIJING and JETSET. There is no matter produced in such events, the hadrons are produced from the fragmentation of strings subsequent to hard collisions. For details on the rapidity dependence see Ref. [1].

[1] V. Koch, A. Majumder, and J. Randrup (2005), nucl-th/0505052.